A HYBRID IMPULSIVE SCHEME FOR FASTER THAN REAL-TIME VEHICLE LOADS PREDICTION

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- A simple real-time model
- Real-time model results
  - Case 1 : Accuracy
  - Case 2 : Stability
- Numerical Temporal Integration
- Hybrid Step Method
  - Theory
  - Generalized Momentum and Impact Solution
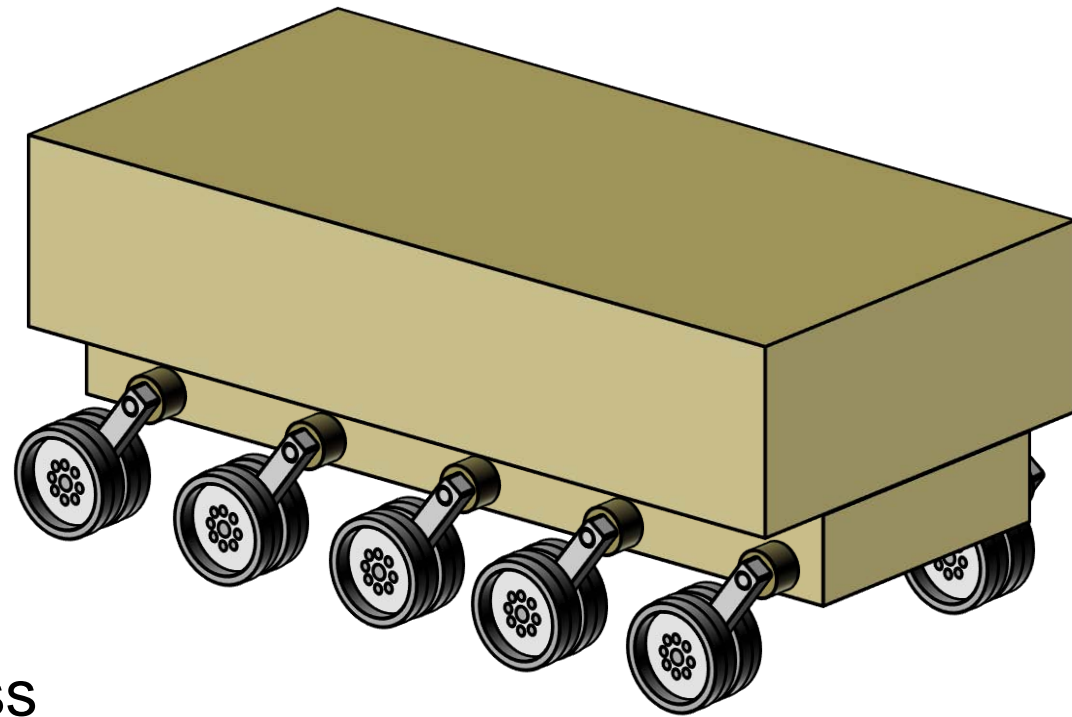 - Finite Time Impulse Results
- Conclusion

Important features:

- **Nonlinear System**
  - Hull orientation
  - Road-arm rotations
- **Ground Contact**
  - Becker law
  - Constant SA
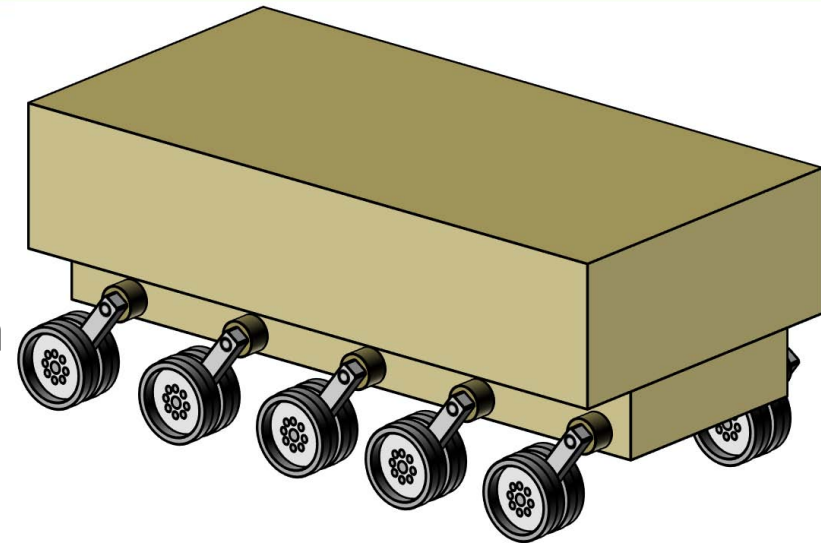- **Jounce Bumper**
  - Exponential stiffness

Tracked Vehicle

Simplifying assumptions:

- Track loop "ignored"
  - Road wheels rotate in unison
  - Specified L/R track speeds
- Ground contact
  - "Spherical" wheels
  - Single point look-up
    - smooth terrain
    - curvature^{-1} >> RW radius.

Tracked Vehicle

MSTV
MODELING and SIMULATION, TESTING and VALIDATION

Force Elements:

$$M_{suspension} = k(\theta - \ell) + c\dot{\theta} + k(e^{(40s)} - 1)$$

$$p = \left(\frac{k_c}{b} + k_\phi\right)z^n$$

$$F_{long} = -F_{normal}c_{soil}(v_{long} - v_{track})$$

$$F_{lat} = -F_{normal}c_{soil}v_{lat}$$

$-\theta$
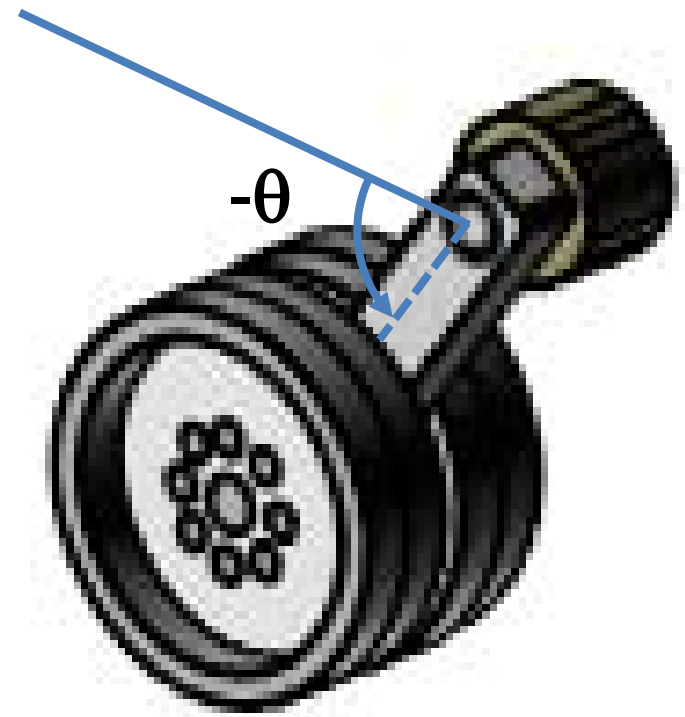
Terrain:

- Scalable bump
- Height, wavelength
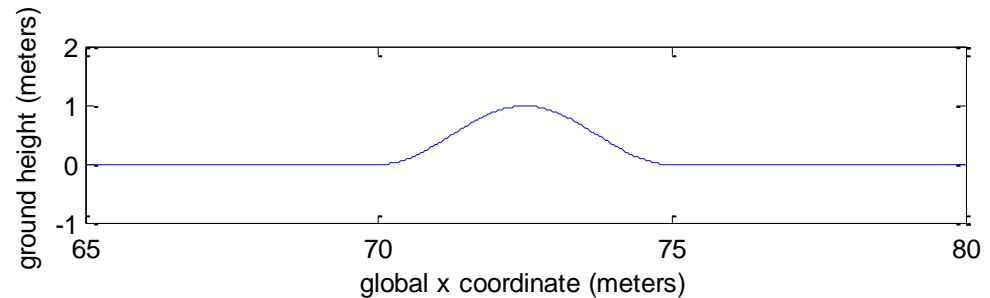
Maneuver:

- Track speeds

Time (sec)	Left speed (m/s)	Right speed (m/s)	Left Acc. (m/s²)	Right Acc. (m/s²)
0	0	0	0	0
3	0	0	0.5	-0.5
4	0.5	-0.5	0	0
5	0.5	-0.5	-0.5	0.5
6	0	0	0	0
7	0	0	2.7	2.7
12	13.5	13.5	0	0

Idle, Pivot, Idle

Bump

Drive
13.5 m/s
(30 mph)
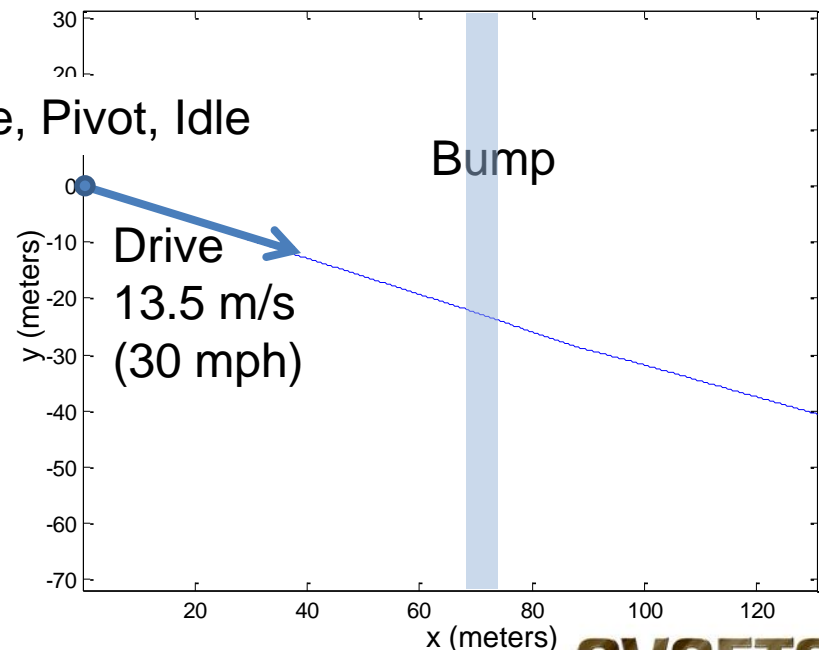
Case 1:

- Model integrated with error control (AS) and at 200 Hz, 500Hz, and 1kHz

- Bump height and wavelength   <1, 5>m

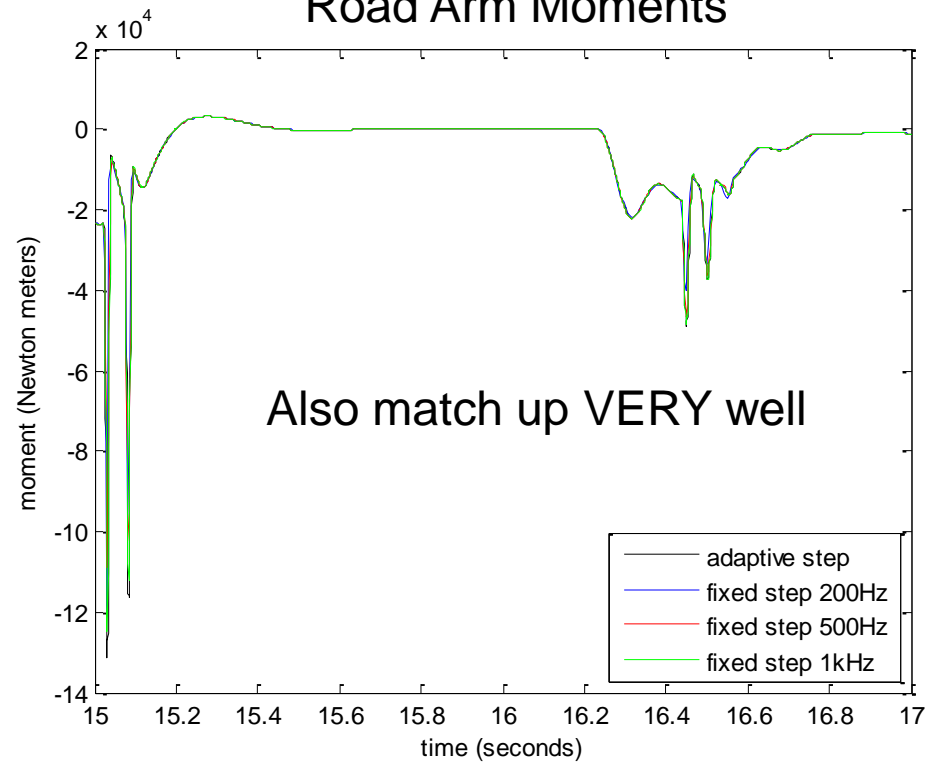- Trajectories are indistinguishable.
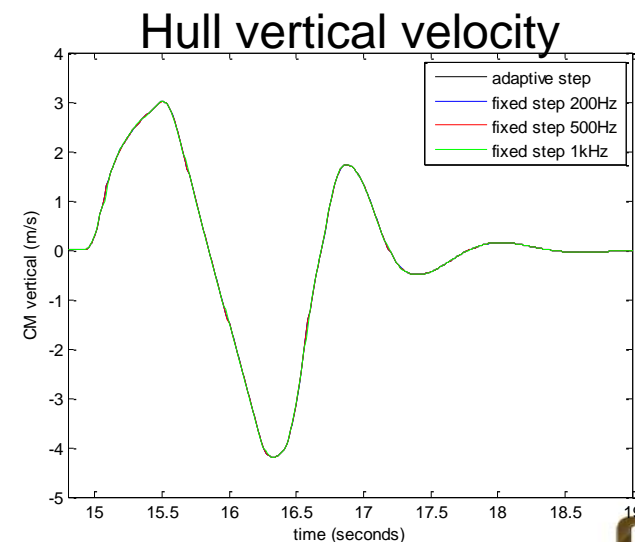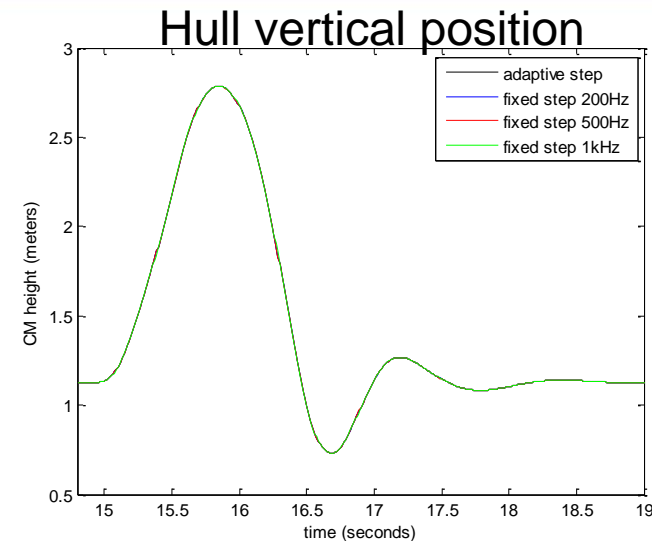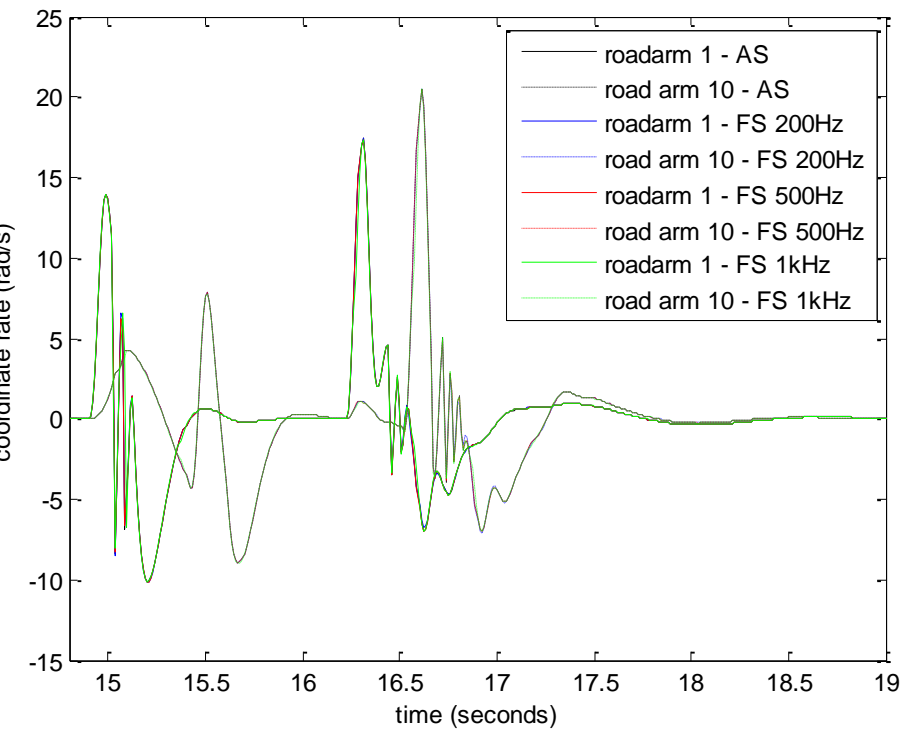
Hull vertical position

Hull vertical velocity

MSTV
MODELING and SIMULATION, TESTING and VALIDATION

Road Arm Rates

Legend:
- roadarm 1 - AS
- road arm 10 - AS
- roadarm 1 - FS 200Hz
- road arm 10 - FS 200Hz
- roadarm 1 - FS 500Hz
- road arm 10 - FS 500Hz
- roadarm 1 - FS 1kHz
- road arm 10 - FS 1kHz

Road Arm Moments

Also match up VERY well

Legend:
- adaptive step
- fixed step 200Hz
- fixed step 500Hz
- fixed step 1kHz

- Peak Loads
  - AS $\quad$ **-1.31×10^5 Nm**
  - 200Hz $\quad$ -1.21×10^5 Nm
  - 500Hz $\quad$ -1.09×10^5 Nm
  - 1kHz $\quad$ -1.25×10^5 Nm

- Results vary chaotically
  - 8%
  - **17%**
  - 5%

Road Arm Moments

- Aliasing also contributes.
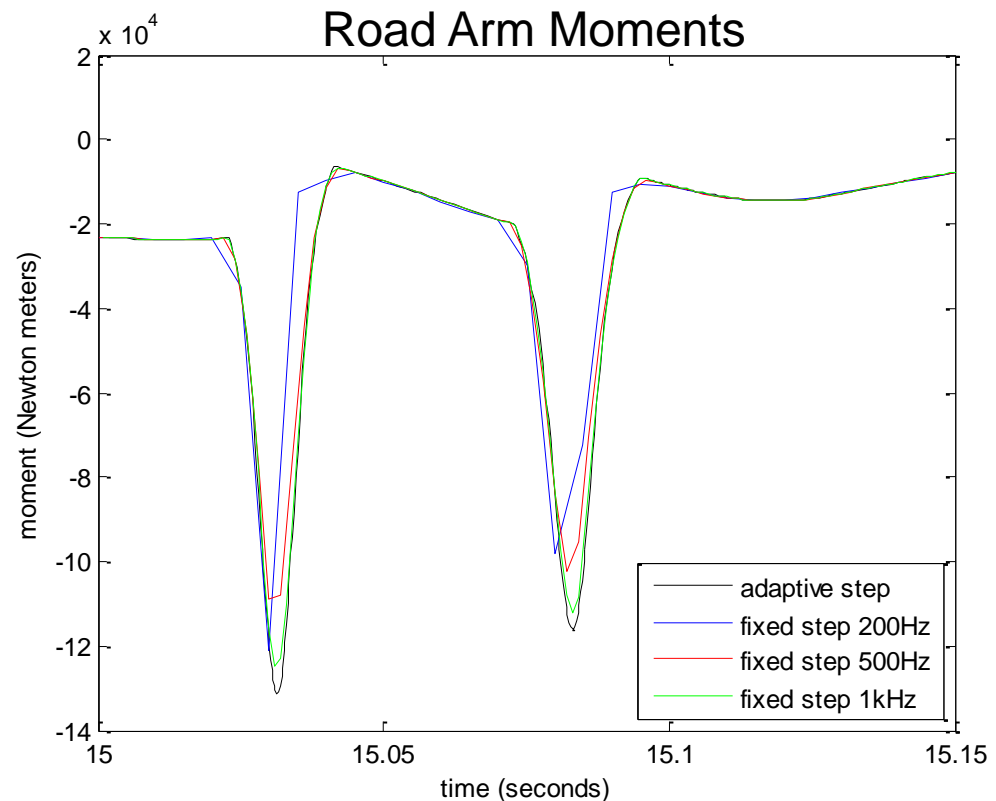
Case 2:

- Again model integrated with error control (AS) and at 200 Hz, 500Hz, and 1kHz

- Bump height and wavelength   **<1, 2>m**

- Initial terrain assumption violated!

- **Results are unstable**.

Hull Vertical Position

Hull Roll Angle
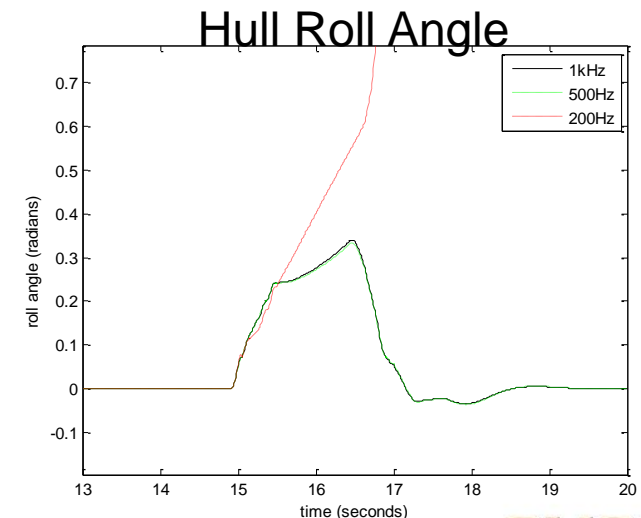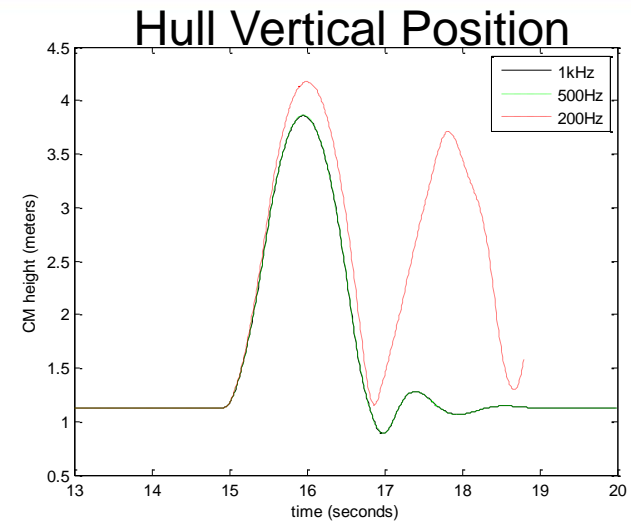
- ## Runge-Kutta family of explicit integrators
  - Forward Euler, RK3, RK4, ode23, ode45, Dormand-Prince, etc.
- ## Basics
  - Approximate: $y(t_0+h)$ where $y' = f(t,y)$
  - Taylor Series Expansion:

$$y(t_0 + h) = y(t_0) + hy'(t_0) + \tfrac{h^2}{2} y''(t_0) + O(h^3)$$

$$y(t_0 + h) = y(t_0) + hf + \tfrac{h^2}{2} \tfrac{df}{dt} + O(h^3)$$

$$\frac{df}{dt} = \frac{\partial f}{\partial y}\frac{dy}{dt} + \frac{\partial f}{\partial t}\frac{dt}{dt} = f_y f + f_t$$

$$y(t_0 + h) = y(t_0) + hf + \tfrac{h^2}{2}(f_t + f_y f) + O(h^3)$$

- Taylor Series Expansion:

$$y(t_0 + h) = y(t_0) + hf + \tfrac{h^2}{2}(f_t + f_y f) + O(h^3)$$

- Function Evaluations:

$$k_1 = f(t_0, y_0) = f$$

$$k_2 = f(t_0 + ha_2, y_0 + hb_{21}k_1) = f + ha_2 f_t + hb_{21}f_y f + O(h^3)$$

- Assembly:

$$y(t_0 + h) = y(t_0) + hw_1 k_1 + hw_2 k_2 + O(h^3)$$

$$y(t_0 + h) = y(t_0) + h(w_1 + w_2)f + h^2 w_2 a_2 f_t + h^2 w_2 b_{21} f_y f + O(h^3)$$

- Constraints defining second order methods:

$$w_1 + w_2 = 1 \qquad w_2 a_2 = w_2 b_{21} = \tfrac{1}{2}$$

Second order methods

$$
\begin{array}{c|cc}
0 & & \\
\alpha & \alpha & \\
\hline
& 1-\frac{1}{2\alpha} & \frac{1}{2\alpha}
\end{array}
$$

Third order method

$$
\begin{array}{c|ccc}
0 & & & \\
\frac{1}{2} & \frac{1}{2} & & \\
1 & -1 & 2 & \\
\hline
& \frac{1}{6} & \frac{2}{3} & \frac{1}{6}
\end{array}
$$

An embedded second order method with α=1/2

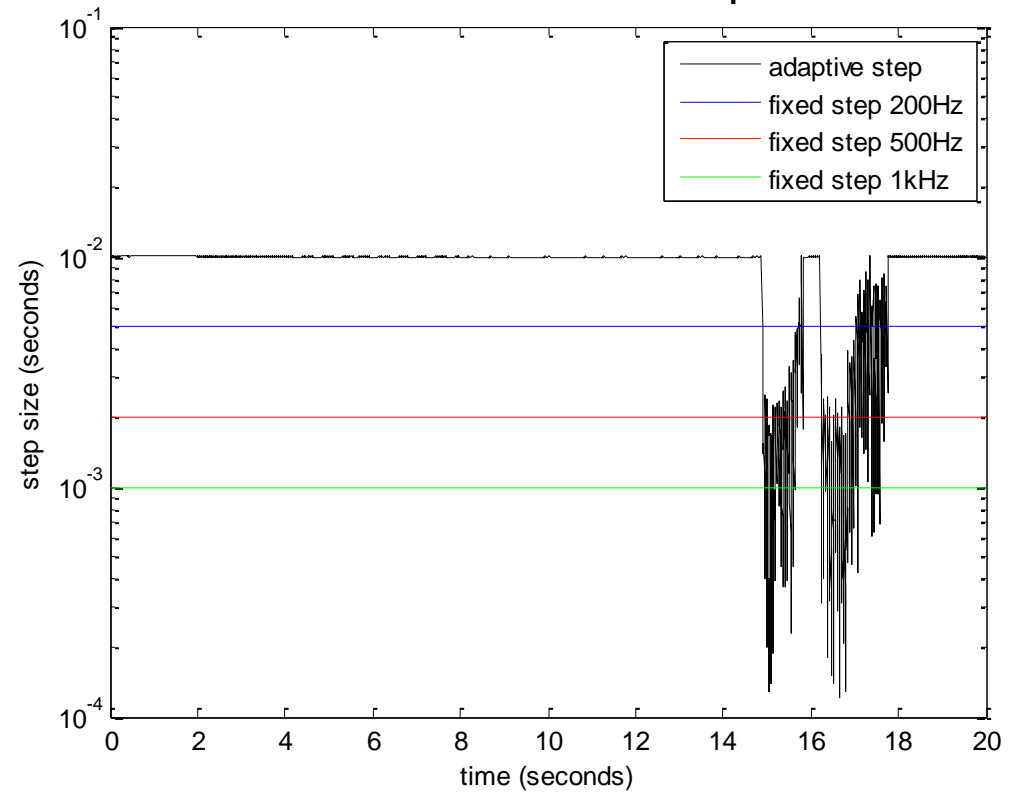Subtraction of two methods approx. error within step.

Error is a state vector difference.

- Application

    – Fixed step

    – Adaptive step

Case 1 Simulation Step Size

Description:

- Use a fixed step integration method.

- Monitor error at each DoF.

- Error exceeding tolerance indicates the system is too stiff to integrate accurately.

- Substitute impulsive event response in zero time.

- Continue integrating.

- Determine accurate loads independently from initial conditions for impulsive event.
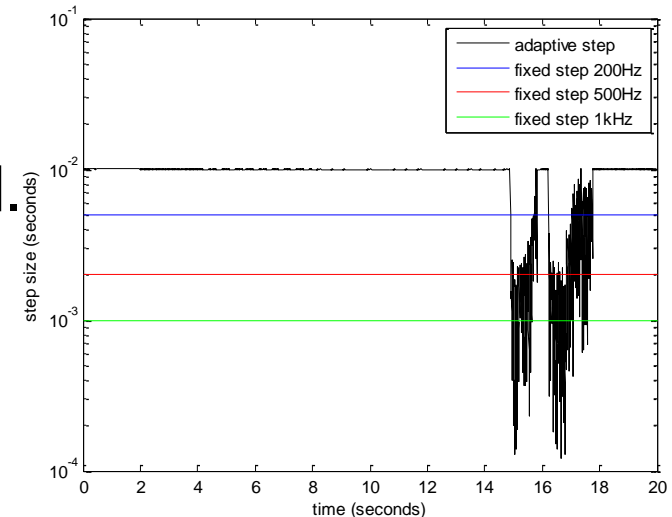
- Generalized Momentum and Impact Solutions:

$$\sum_i \left(m_i v_i^+ \cdot \frac{\partial v_i}{\partial u_r} + I_i \cdot \omega_i^+ \cdot \frac{\partial \omega_i}{\partial u_r} \right) - F_c \Delta t \cdot \frac{\partial v_c}{\partial u_r} =$$

$$\sum_i \left(m_i v_i^- \cdot \frac{\partial v_i}{\partial u_r} + I_i \cdot \omega_i^- \cdot \frac{\partial \omega_i}{\partial u_r} \right)$$

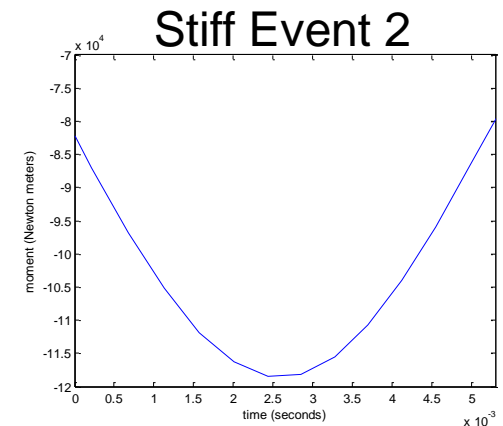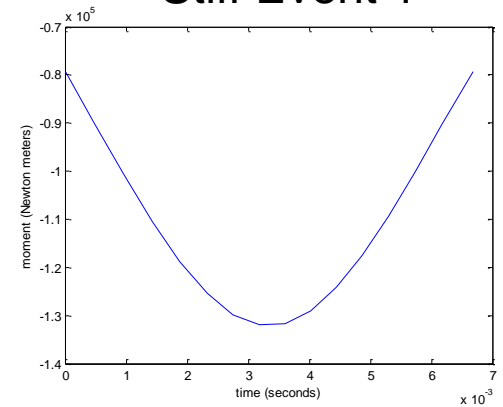$$v_c^+ \cdot \hat{n} = -\varepsilon v_c^- \cdot \hat{n}$$

DESIRED Loads Method

Hybrid Impulsive Load Time History

Road Arm Moments
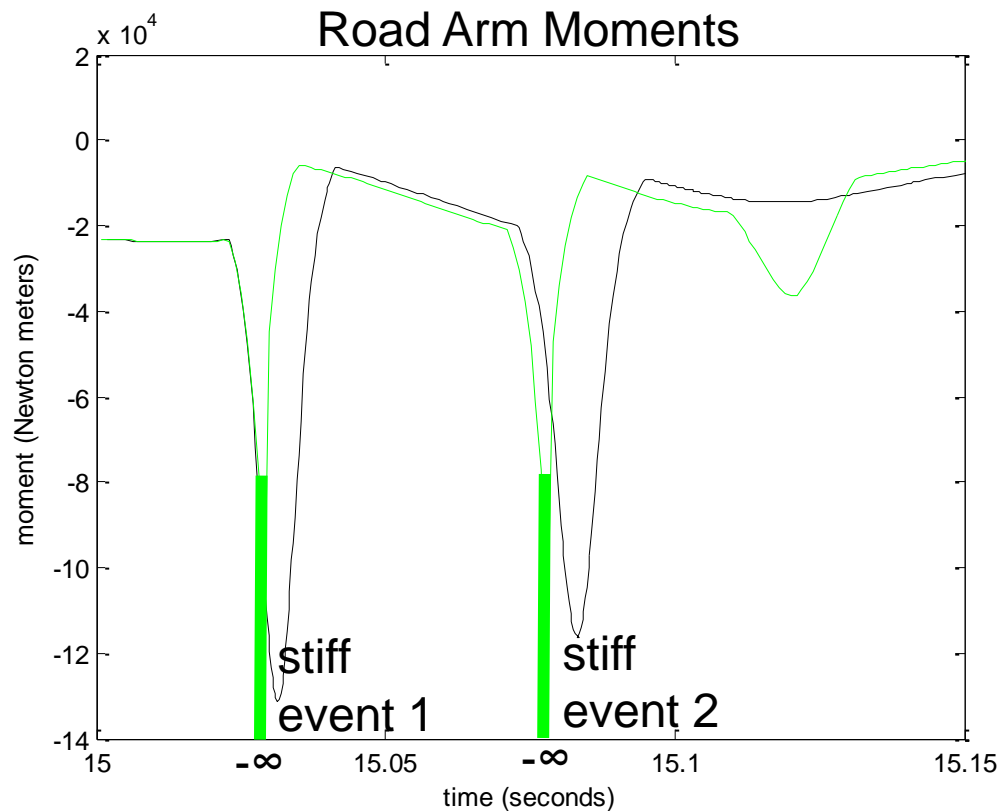
External Integration
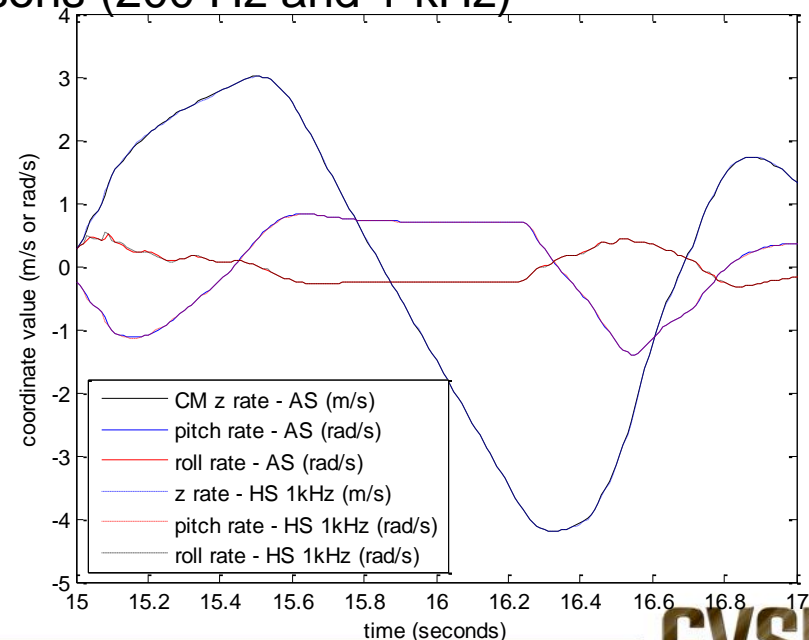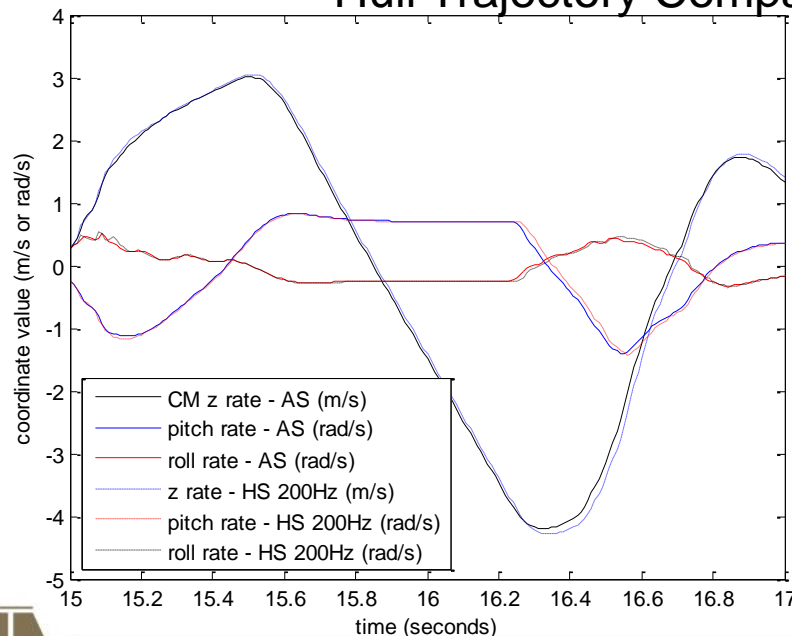

Stiff Event 1

Stiff Event 2

Didn't quite get there

Applied Finite Time Impulses

- A compromise, in some sense a more "general" solution.
  - Modeling the design intent of a component throughout a stiff region with prescribed motion constraint.
  - Peak loads reconstructed using initial conditions for impulse.

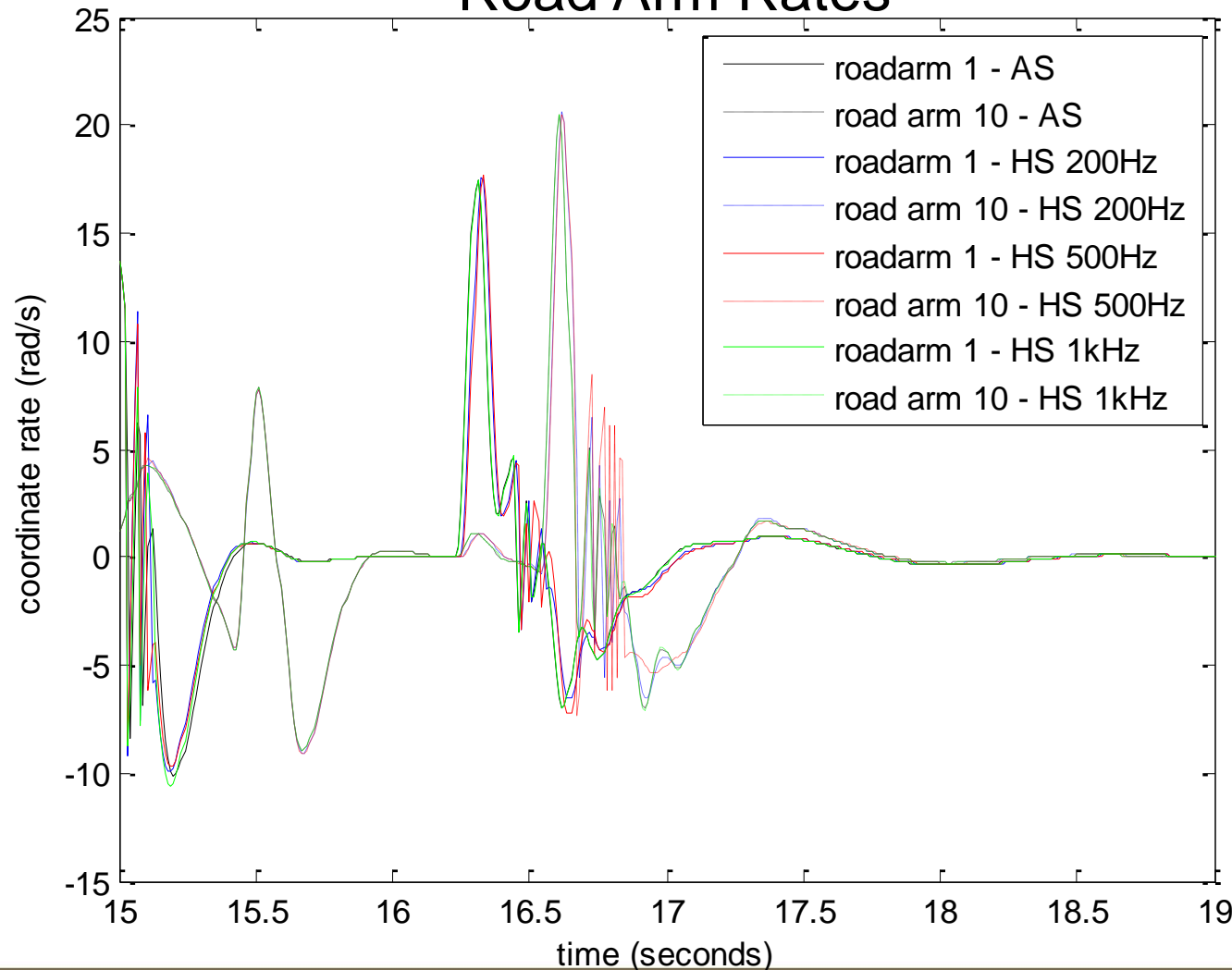Hull Trajectory Comparisons (200 Hz and 1 kHz)

Road Arm Rates

COR = 1
Better values
needed

Road Arm Rates
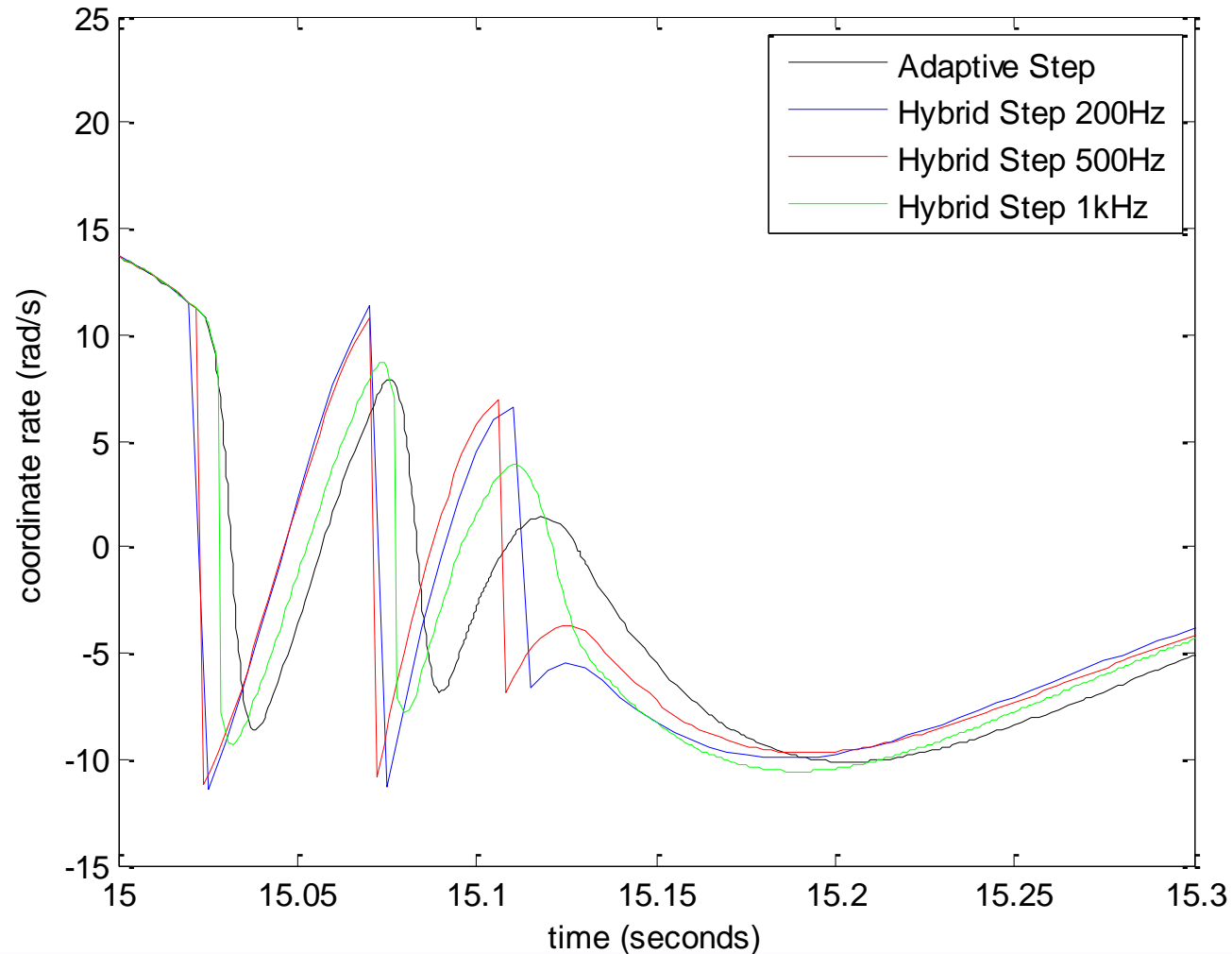
COR = 1
Better values
needed
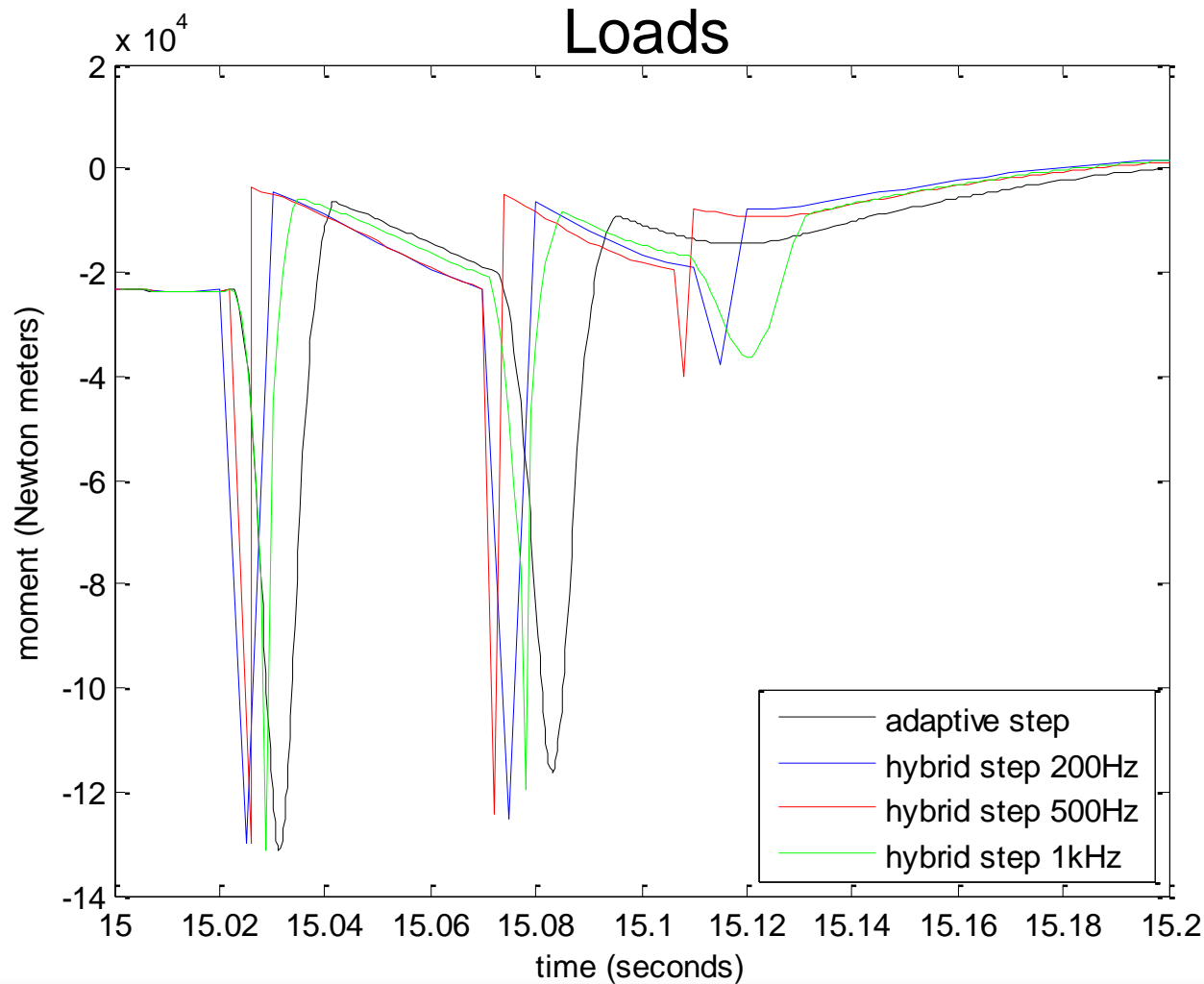
Loads

- A new method for rapid loads evaluation has been presented in combination with real-time requirements.

- Stiffness is identified dynamically rather than geometrically (no contact detection).

- Zero time events proved difficult and are the subject of on going work.

- Finite time impulses
  - Have broader/easier application.
  - Peak loads may be post processed off-line and independently.